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# Digitally reproduced dental casts: Validating the duplication of dental casts utilizing 3D digital scanners and a 3D printer system

**Lamia Almutairi**[1✉], **Bushra Alotaibi**[1], **Sarah Alkhattab**[1], **Mohammed Awawdeh**[2]

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**Author Affiliation:**
[1]Bachelor of Dental Sciences student, College of Dentistry, King Saud bin Abdulaziz University for Health Sciences, Riyadh, Saudi Arabia
[2]Assistant professor at College of Dentistry, King Saud bin Abdulaziz University for Health Sciences, Riyadh, Saudi Arabia

✉**Corresponding author**
Bachelor of Dental Sciences student, College of Dentistry, King Saud bin Abdulaziz University for Health Sciences,
Riyadh, Saudi Arabia
Email: lamiasalem06@gmail.com

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## ABSTRACT

*Purpose*: To evaluate the efficiency between three different scanners in the College of Dentistry in King Saud bin Abdulaziz University for Health Sciences (KSAU-HS) in terms of obtaining accurate 3D models. *Methodology*: Five pairs of plaster casts were selected randomly from the clinics of KSAU-HS. The casts were scanned using three different 3D scanners to create 3D models and printed using a 3D printer. Mesh Lab 2016 software was used to evaluate the accuracy of the printed models by superimposing the original scanned casts on the printed casts. A hand held calliper was used to measure selected distances to compare between the plaster casts and the printed models. *Results*: Statistical analyses were done using Graph Pad Prism 5. Kruskal-Wallis test showed no statistically significant difference in the accuracy between the scanners, $P=.166$. K-related test for the manually measured casts showed no statistically significant difference in the accuracy between the scanners, $P=.433$. The three scanners showed substantial differences in terms of scanning time. *Conclusion*: No variations were detected in the accuracy of the printed and original models.

**Keywords**: 3D printer, 3D scanner, dimensional accuracy, superimposition software, orthodontic cast

## 1. INTRODUCTION

Obtaining dental records is a major step in all dental specialties for both treatment planning and legal medical issues. For decades, many branches of dentistry were dependent on the use of dental impressions to fabricate plaster casts. In recent years, the development of digital technology has been significant in multiple fields in dentistry, such as orthodontics, prosthodontics, and dental implants. Dental clinics are expanding the usage of 3D technology such as 3D digital scanners and 3D printers due to the multiple advantages they provide. Digital technology offers improved experience for

the patients by avoiding the usage of the unpleasant alginate impression material (Ghoneima et al., 2018). One of these technologies is 3D printers. Using this technology in orthodontic practice and obtaining more precise and accurate modelling has become possible. According to the ISO-5725, accuracy consists of two different aspects, trueness and precision (Sim et al., 2018). Trueness can be defined as how close the experimental result is to the true value. Thus, obtaining high trueness means that the experimental result is equivalent or very close to the true value. Precision indicates the closeness of intragroup data (Sim et al., 2018). 3D dental casts obtained by 3D digital models have been shown by multiple studies to have the same precision and accuracy as the measurements obtained by plaster casts, which means they could be used as an alternative for those traditional plaster casts (Firestone et al., 2004; Fleming et al., 2011; Huggare et al., 2003; Kasparova et al., 2013; Major et al., 2006; Sohmura et al., 2000; Tomassetti et al., 2001).

There are few studies that compare the accuracy of printed models with plaster models. These studies conclude that the printed models can be used instead of plaster models (Camardella et al., 2017; Kasparova et al., 2013; Knox et al., 2008; Ren et al., 2014; Saleh et al., 2015). The reason for discussing the usage of digital models as an alternative for plaster casts is the disadvantages of plaster casts, such as their heavy weight, risk of breakage or damage, and challenges to storage and data-sharing with other professionals (Kasparova et al., 2013). This study purpose was to measure the accuracy (trueness and precision) of 3D-printed models obtained using three different scanners by comparing them with the traditional plaster casts. The hypothesis of this study was, among the 3D-printed and traditional cast models, no significant difference would be found in their accuracy.

## 2. MATERIALS AND METHODS

This study was reviewed by the King Abdullah International Medical Research Centre Institutional Review Board and was deemed exempt under IRB protocol RYD-19-419812-151792. The Study Duration is September 2019 – October 2020.

In this study, five pairs of plaster casts (10 plaster casts of upper and lower jaws) were randomly selected from the clinics of the College of Dentistry at KSAU-HS. All the plaster casts were formed using gypsum and were taken from orthodontic clinic patients. The casts were numbered from one to five (as pairs). All the plaster casts showed full arches with no breakage, surface damage, or missing teeth. However, as commonly seen with orthodontic cases, there were some orthodontic anomalies. To create 3D digital models, three different scanners were used. The Semi-Automatic KaVo ARCTICA 3D scanner is characterized by manual setting of the scanning angle and comes with multi CAD dental CAD computer software to display a live image. The inEos X5 scanner works using short-wavelength blue light and contains a rotational arm to optimally align, position, and scan the cast from different planes. The Ceramill Map 400 scanner works with an inLabBiogeneric software and Ceramill Mind software to visualize the scanned cast. All the scanners were used for all samples with the same protocol. The time each scanner took during the process is shown in Table 1.

**Table 1** Estimated time for each scanner.

| | Models | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Scanner | *Time* | | | | | | | | | | *Average* |
| KAVO | 4.11 | 3.58 | 3.18 | 3.13 | 3.35 | 3.15 | 3.32 | 3.21 | 3.16 | 3.27 | 3.53 |
| Ceramill | 8.25 | 7.43 | 7.37 | 6.48 | 6.08 | 4.27 | 9.29 | 11.03 | 8.53 | 6.53 | 7.55 |
| inEos X5 | 2.57 | 5.59 | 4.00 | 6.15 | 5.00 | 4.20 | 4.41 | 3.40 | 3.50 | 5.00 | 4.38 |

Note: It has been noticed that the position and anomalies of the teeth affect the scanner time.

Each scanner software saves 3D digital images in standard tessellation language (STL). Utilizing the STL data, the casts were reproduced by the 3D printer. All plaster casts were printed using a ProJet MJP 3600 3D printer. For the printing, three steps were followed: data preparation (the scanner name and the number of the model were engraved on the cast, fixed, and splinted to the digital image), printing preparation (orientation of the casts so 19 models (10 from KaVo ARCTICA 3D scanner and 9 from Ceramill Map400 scanner) were printed at a time, and the queue (printing). There are many materials that may be used with the printer, but two types were used in this research. The supporting material VisiJet S300 (wax) was used as a base material for the shape formation. VisiJet M3 Dentcast (colorless) was used for building the model. The printing time depends on the height of the model. Thus, all the plaster casts were trimmed before scanning to reduce the time and the used materials. The estimated printing time for the first printed models was 20 h and 33 min with an estimated 0.544 Kg of Dentcast and 0.706 Kg of VisiJet S300. The second group

of 18 models (9 from Ceramill Map400 and 9 from inEos X5) took 24 h and 0 min and used 0.731Kg of Dentcast and 1.044Kg of VisiJet S300.

The printed models were put in a ProJet Finisher Oven so the excess wax melted at 80°C for about one hour (Figure 1). After printing and scanning, all the printed and plaster models were measured. Figure 2 provides an illustration of the design of the study. Two different measuring methods were followed. First, each printed model was compared to the original model by superimposing the STL files of both models using the MeshLab 2016 software, well-repeated software. It completed several iterations and eventually gave the average error, and the conversions happened when the difference between two consecutive iterations was less than 0.01. Three different operators used this software to evaluate the models. Six main points were agreed on to use as a reference so that the software could perform the superimposition step effectively. The points were the lingual cusp of both second premolars, the canines cusp tip, and the distal side of the central incisors incisal edge. This software eliminates any human errors and removes any intra-operator or inter-operator bias. Another data collection method was to manually measure the casts using the digital handheld calliper. The measurements were done by two different operators on the selected dimensions (inter molars, premolars, and canines spaces). For the statistical analysis of the results, a Kruskal-Wallis test was performed for data obtained from the MeshLab 2016 software and the time that each scanner took during the process of scanning, and a Friedman test for the manual measurements was also performed.

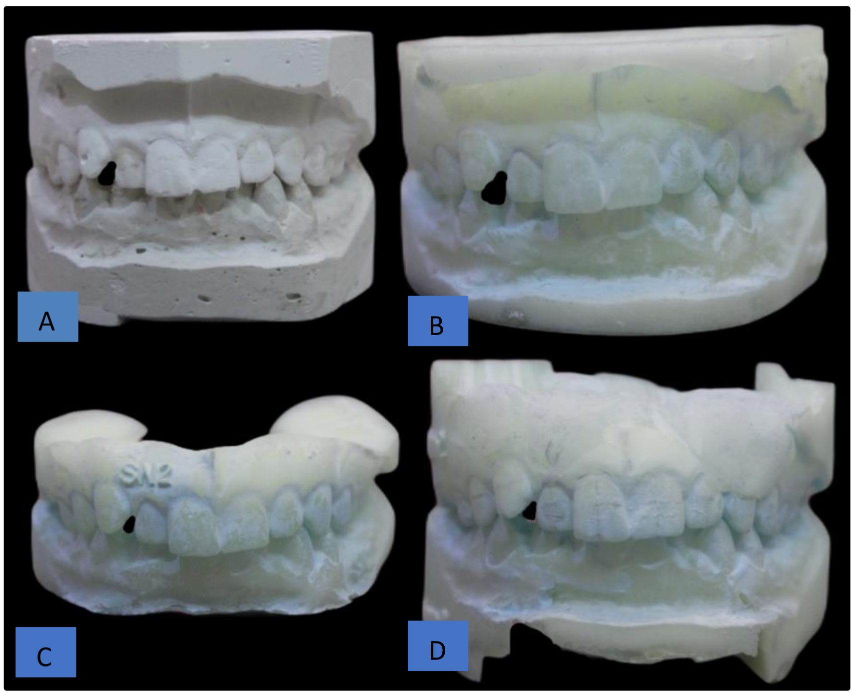


**Figure 1** Original plaster cast (A). Printed models after finishing: (B) Kavo, (C) inEos X5, and (D) Ceramill.

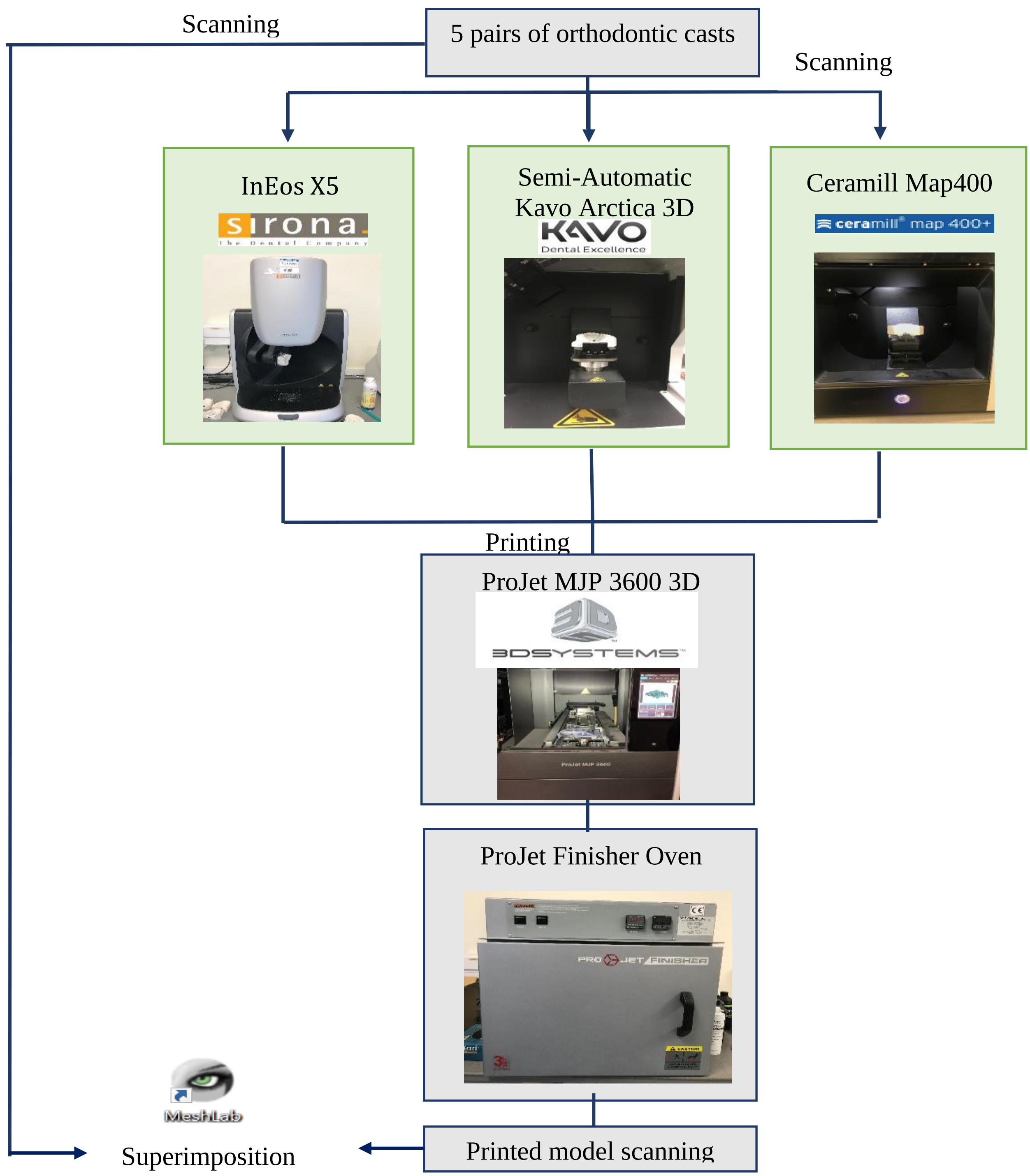


**Figure 2** Schematic of the design of this study

## 3. RESULTS

Analyses were done using GraphPad Prism 5 application with a standard confidence interval of 95% corresponding to an alpha of 0.05 for all the analyses. Three methods were used to assess the accuracy: the average of errors of the software, manual measurements obtained from a handheld calliper, and the models scanning time.

**Average of error obtained from MeshLab software**

For the average error, there was a significant difference between the scanners as KaVo ARCTICA 3D had a significant lower value than the other two scanners (Figure 3). However, according to the Kruskal-Wallis test, there is no significant difference in the

median of all the scanners; the median P-value was 0.1655, with a confidence level of 95%. Also, the median did not vary significantly with Dunn's multiple tests. The standard deviation values for the average error were less than 0.5 mm (Table 2).

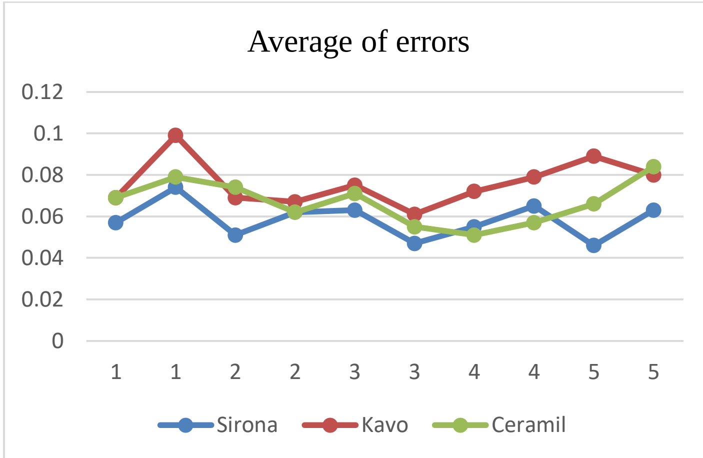


**Figure 3** Average error of the superimposition using MeshLab 2016 software

**Table 2** Mean and standard deviation of each scanner.

| Scanner | N | *M* | *SD* |
|---|---|---|---|
| Ceramill | 10 | .06 | .01 |
| Kavo | 10 | .05 | .02 |
| inEos X5 | 10 | .05 | .00 |

**Manual Measurements**

In the manual measurement of different points illustrated in Table 3 and Figure 4, KaVo ARCTICA 3D, Ceramill Map 400, inEos X5, and the original models had a P-value = *.433*. A nonparametric test (k-related samples) was used to determine the data significance. The data of this research suggest that there is no significant difference between the traditional plaster casts and the printed models.

**Table 3** Handheld digital calliper measurements.

| *Measurement* | *Cast* | *Kavo* | *Ceramill* | inEos X5 | *Original* | *Model* |
|---|---|---|---|---|---|---|
| Inter canine | 1 | 35.51 | 35.06 | 36.29 | 36.29 | 1 |
| Inter canine | 2 | 28.35 | 28.54 | 28.54 | 28.44 | 1 |
| Inter canine | 1 | 36.25 | 36.42 | 36.69 | 36.59 | 2 |
| Inter canine | 2 | 24.55 | 24.54 | 24.31 | 24.37 | 2 |
| Inter canine | 1 | 35.32 | 35.14 | 35.18 | 35.55 | 3 |
| Inter canine | 2 | 26.29 | 26.23 | 26.11 | 26.25 | 3 |
| Inter canine | 1 | 39.64 | 40.03 | 39.28 | 39.73 | 4 |
| Inter canine | 2 | 29.77 | 28.94 | 28.94 | 30.47 | 4 |
| Inter canine | 1 | 32.6 | 32.4 | 32.45 | 32.49 | 5 |
| Inter canine | 2 | 25.04 | 24.9 | 24.42 | 24.86 | 5 |
| Inter 1st premolar | 1 | 29.79 | 29.37 | 29.36 | 29.41 | 1 |
| Inter 1st premolar | 2 | 29.38 | 28.96 | 28.77 | 28.97 | 1 |
| Inter 1st premolar | 1 | 31.75 | 31.48 | 31.68 | 31.91 | 2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Inter 1st premolar | 2 | 28.46 | 28.14 | 28.18 | 28.69 | 2 |
| Inter 1st premolar | 1 | 30.92 | 30.96 | 31.34 | 31.12 | 3 |
| Inter 1st premolar | 2 | 26.86 | 26.93 | 27.39 | 26.79 | 3 |
| Inter 1st premolar | 1 | 34.8 | 34.78 | 34.52 | 34.59 | 4 |
| Inter 1st premolar | 2 | 29.34 | 29.48 | 29.49 | 29.06 | 4 |
| Inter 1st premolar | 1 | 31.08 | 31.11 | 31.11 | 31.16 | 5 |
| Inter 1st premolar | 2 | 25.52 | 25.65 | 25.73 | 25.5 | 5 |
| Inter 2nd premolar | 1 | 47.42 | 47.93 | 47.97 | 47.89 | 1 |
| Inter 2nd premolar | 2 | 43.46 | 43.54 | 43.77 | 43.47 | 1 |
| Inter 2nd premolar | 1 | 49.49 | 49.25 | 49.2 | 49.35 | 2 |
| Inter 2nd premolar | 2 | 38.02 | 38.77 | 38.78 | 38.72 | 2 |
| Inter 2nd premolar | 1 | 48.14 | 48.33 | 48.66 | 48.73 | 3 |
| Inter 2nd premolar | 2 | 41.97 | 41.78 | 42.05 | 42.32 | 3 |
| Inter 2nd premolar | 1 | 48.34 | 48.49 | 48.72 | 48.79 | 4 |
| Inter 2nd premolar | 2 | 39.09 | 40.35 | 40.22 | 40.16 | 4 |
| Inter 2nd premolar | 1 | 47.56 | 47.48 | 47.46 | 47.73 | 5 |
| Inter 2nd premolar | 2 | 38.77 | 38.61 | 38.16 | 38.58 | 5 |
| Inter 1st molar | 1 | 39.82 | 40.02 | 39.66 | 39.66 | 1 |
| Inter 1st molar | 2 | 34.74 | 34.29 | 34.92 | 34.7 | 1 |
| Inter 1st molar | 1 | 38.42 | 38.14 | 38.1 | 38.52 | 2 |
| Inter 1st molar | 2 | 31.13 | 31.18 | 31.31 | 31.25 | 2 |
| Inter 1st molar | 1 | 42.81 | 42.28 | 42.84 | 42.38 | 3 |
| Inter 1st molar | 2 | 36.8 | 36.01 | 36.82 | 36.62 | 3 |
| Inter 1st molar | 1 | 39.75 | 39.34 | 39.66 | 39.51 | 4 |
| Inter 1st molar | 2 | 32.5 | 32.55 | 32.44 | 33.16 | 4 |
| Inter 1st molar | 1 | 40.43 | 40.93 | 40.93 | 40.92 | 5 |
| Inter 1st molar | 2 | 33.5 | 33.67 | 33.89 | 33.57 | 5 |

Note: k-related sample was used to determine the significance of the data. Number 1 in the cast column stand for upper cast and number 2 stand for lower cast.

**Figure 4** Selected distances for handheld digital calliper

**Scanning Time**

In regard to the time, there is a significant difference between the scanners in reference to their medians. According to Kruskal-Wallis test, the P-values were less than 0.0001, which is significant in relation to $P < 0.05$. Upon further analyses using Dunn's multiple comparisons for intergroup relations, there was no significant difference between KaVo ARCTICA 3D and inEos X5, but there was a significant difference between KaVo ARCTICA 3D and Ceramill Map 400, as well as inEos X5. Hence, there is a significant difference between the scanners regarding scanning time.

Upon review of all the parameters, the software average of error and manual measurement, there is evidence to support that there is no significant difference between the 3D-printed models and traditional plaster casts regarding their accuracy, with a confidence level of 95%. This is contrary to the time aspect.

## 4. DISCUSSION

This study compared three different 3D scanners in terms of effectiveness in the production of accurate 3D-printed models and the produced models accuracy. Evaluation of the accuracy was done by three means. One, model super imposition with MeshLab software. Two, three investigators measured certain linear distance in both models (original, printed) (Figure 4). Three, scanning time of the three different scanners. With respect to the scanners type,the average of error produced by the MeshLab software showed no significant difference between inEos X5 and Ceramil Map 400; however, statistically significant difference was reported with KaVo ARCTICA 3D having a lower average of error. This difference is insignificant clinically since it is below 1 mm. The usage of 3D scanners to provide templates for digital models from traditional plaster casts was followed by this research and Kasparova et al., (2013) concluded that using 3D printers can replace the traditional plaster casts primarily due to their accuracy. Another study measured the accuracy of printed dental models made with different designs of model bases and reported that printed models whether with a regular base or a horseshoe-shaped base were accurate regardless of the printing technique used (Camardella et al., 2017). This supports these research findings. The second evaluation tool in this study is the manual measurements of certain points in the two models (original plaster cast and printed model). According to the findings of this research, there was no significant difference between the traditional plater cast and the printed models. The time factor was used to assess the efficiency of the 3D scanners to produce the printed models. The findings showed that there was a difference between the KaVo ARCTICA 3D and the Ceramill Map 400, as well as the inEos X5. Hence, there is a significant difference between the scanners in regard to the scanning time. One of the great implications for determining dental model prototyping accuracy is the lack of studies that define the acceptable measurement differences range, which is a topic for future studies (Ghoneima et al., 2018). Digital and plaster models and defined 0.50 mm as the clinically acceptable range of difference, while other studies have used 0.20–0.50 mm as an acceptable range of difference (Ayoub et al., 2003; Cho et al., 2015; Hassan et al., 2017; Hirogaki et al., 2001; Ren et al., 2014).

Further studies and investigations are warranted in the field of different superimposition software in terms of efficiency, quality, and price. There is lack of information of the different superimposition software available in the market. The currently available software is usually sponsored by manufacturers which could affect the truthfulness of the studies. One of the difficulties faced in this study is the need to adjust some of the STL files to be able to print the models. The problem was especially faced with inEos X5 scanner files in the first trial of printing; they had missing bases and were of poor quality. Another factor to keep in mind to reduce

the printing time and to preserve the expensive printing materials is to remove a layer from the base of the digital plaster cast. This will save hours of printing and large amount of materials.

## 5. CONCLUSION

In conclusion, 3D printers and 3D scanners are precise and reliable tools to reproduce dental casts. After using two methods to measure and evaluate the accuracy of printed models, the results show a similar conclusion. Kruskal-Wallis test and the Friedman test showed no statistically significant difference in accuracy and precision between the printed models and the traditional models. Between the three scanners (KaVo ARCTICA 3D, inEos X5, and Ceramill Map 400) there is a significant difference in terms of time. KaVo ARCTICA 3D scanner was the fastest scanner. Using 3D printers and scanners offer more benefits than traditional methods. They can replace traditional methods due to their accuracy and precision as confirmed in this research.

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**Authorship contribution statement**

Lamia Almutairi: Data curation, Investigation, Methodology, Resources, Software, Writing-original draft.
Bushra Alotaibi: Data curation, Investigation, Methodology, Resources, Software, Writing - review &editing.
Sarah Alkhattab: Data curation, Investigation, Methodology, Resources, Software, Writing - review &editing.
Mohammed Awawdeh: Conceptualization, Supervision, Project Administration, Validation

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**Conflict of Interest**

The authors declare that there are no conflicts of interests.

**Data and materials availability**

All data associated with this study are present in the paper.

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